SEDUTA DEL COLLEGIO DEI DOCENTI DEL 38°-39°-40°-41° CICLO
23 ottobre 2025

Il Collegio dei Docenti del Dottorato di Ricerca in Scienze Fisiche e Chimiche dell'Università di Palermo, dei cicli 38, 39, 40 e 41, regolarmente convocato in modalità telematica dal Coordinatore Prof. Marco Cannas, si riunisce sulla piattaforma Microsoft Teams alle ore 14,30 del giorno 23.10.2025 con il seguente ordine del giorno:

1) **Esame finale di conseguimento del titolo di dottore di ricerca (criteri per l'attribuzione della lode)**
2) **Adempimenti per l'esame finale di conseguimento del titolo di dottore di ricerca del 38° ciclo (I° sessione)**
3) **Provvedimenti allievi (attività didattica integrativa)**
4) **Ratifica decreti**
5) **Varie ed eventuali**

Presiede il Coordinatore Prof. M Cannas, svolge le funzioni di segretario il Prof. Simonpietro Agnello.

Sono presenti

Marco Cannas, Simonpietro Agnello, Alberto Pettignano, Alice Sciortino, Marco Miceli, Francesco Ciccarello, Fabrizio Messina, Angelo Carollo, , Francesco Giannici, Tiziana Di Salvo, Francesco Ferrante, Serena Benatti, Michelangelo Scopelliti, Lucia Rizzuto, Mauro Paternostro, Fabrizio Lo Celso, Melania Del Santo, Giovanni Marsella, Gioacchino Massimo Palma, Roberto Passante, Salvatore Micciché, Rosario Iaria, Antonino D'Ai, Luca Innocenti, Gianpiero Buscarino, Davide Valenti, Lorenzo Lisuzzo, Giuseppe Cavallaro, Manuela Mallamaci

Sono assenti giustificati

Stefana Milioto, Fabio Bagarello, Giuseppe Lazzara, Fabio Reale, Claudio Fazio, Luciano Burderi, Paolo Pagano, Umberto De Giovannini, Giuseppina Micela, Salvatore Lorenzo.

È inoltre presente il Dott. Ciro Pinto in qualità di cotutor.

Il Presidente, prof. M. Cannas, verificato il numero legale, dichiara aperta la seduta

1) **Esame finale di conseguimento del titolo di dottore di ricerca (criteri per l'attribuzione della lode)**

Il presidente informa che nel nuovo regolamento dei corsi di dottorato di UNIPA (art. 17) la commissione dell'esame finale, con voto unanime, ha facoltà di attribuire la lode in presenza di risultati di particolare rilievo scientifico.

Il presidente invita il collegio a stabilire dei requisiti minimi che l'allievo candidato deve soddisfare per essere eleggibile all'attribuzione della lode.

Dopo ampia discussione, il collegio propone che l'eleggibilità alla lode debba tenere conto dei giudizi dei referee esterni. In particolare, rispetto alle 5 voci che sintetizzano il livello del lavoro di tesi: *1) Technical quality; 2) Novelty, 3) Relevance; 4) Clarity of presentation; 5) Quality of scientific production*, è necessario che il giudizio sia eccellente in almeno quattro di esse; in ogni caso, la voce *Quality of scientific production* deve sempre raggiungere il livello di eccellenza.

Il collegio invita il coordinatore di informare preliminarmente la commissione finale qualora i candidati soddisfino o meno i requisiti minimi per l'attribuzione della lode.

Il Collegio dei Docenti **approva all'unanimità** la proposta emersa dalla discussione.

2) Adempimenti per l'esame finale di conseguimento del titolo di dottore di ricerca del 38° ciclo (I° sessione)

Il presidente illustra gli adempimenti necessari per il conseguimento del titolo di dottore di ricerca per gli allievi del 38° ciclo che intendono sostenere l'esame finale nella prima sessione (15 Novembre – 19 Dicembre 2025).

In accordo al cronoprogramma. il presente collegio dei docenti dovrà occuparsi dei seguenti punti:

- formulazione della relazione del dottorando sulle attività svolte

- formulazione del parere per il titolo di Doctor Europaeus

- proposta di formazione delle commissioni giudicatrici

- nomina dei valutatori esterni

Allievo Barra Francesco

(Tutor: Prof. ssa Tiziana Di Salvo; Cotutor: Dr Ciro Pinto)

Il collegio prende visione della relazione dell'allievo (**allegato 1 al verbale**).

Il collegio propone che la commissione giudicatrice per l'esame finale sia composta da:

Membri effettivi

1) Prof. Rosario Iaria, Università degli Studi di Palermo, rosario.iaria@unipa.it

2) Prof. Andrea Tiengo, IUSS Pavia, andrea.tiengo@iusspavia.it

3) Dr. Domitilla de Martino, INAF Osservatorio di Napoli, domitilla.demartino@inaf.it

Membri Supplenti:

Prof. Marco Miceli, Università degli Studi di Palermo

Prof. Paolo Esposito, IUSS Pavia

Il collegio nomina i valutatori esterni:

1) Dr. Matteo Bachetti, INAF Osservatorio di Cagliari, email: matteo.bachetti@inaf.it

2) Dr. Jakob van den Eijnden, University of Amsterdam, email: a.j.vandeneijnden@uva.nl

Allievo Favitta Amedeo Maria

(Tutor: Prof. Roberto Passante; Cotutor: Prof.ssa Lucia Rizzuto)

Il collegio prende visione della relazione dell'allievo (allegato 2 al verbale).

Il collegio propone che la commissione giudicatrice per l'esame finale sia composta da:

Membri effettivi

1) Prof. Rosario Iaria, Università degli Studi di Palermo, rosario.iaria@unipa.it

2) Dr. Riccardo Messina, Laboratoire Charles Fabry (CNRS, Institut d'Optique Graduate School, Université Paris-Saclay

3) Prof. Alessessandro Mirizzi, Università di Bari Aldo Moro

Membri Supplenti:

Prof.ssa Tiziana Di Salvo, Università degli Studi di Palermo

Prof.ssa Patrizia Vitale, Università degli Studi di Napoli

Il collegio nomina i valutatori esterni:

1) Dr. Luca Di Luzio, INFN, Sezione di Padova, email: luca.diluzio@pd.infn.it

2) Prof. Akbar Salam, Wake Forest University, Winston-Salem, NC (USA), email: salama@wfu.edu

3) **Provvedimenti allievi (attività di didattica integrativa)**

Il presidente informa di avere ricevuto la richiesta di Nulla Osta da parte del Dott. Emanuele SANGIORGI, allievo del Dottorato di Ricerca in Scienze Fisiche e Chimiche (38° ciclo), svolgere attività didattica integrativa, per un totale di 28 ore, nell'ambito delle esercitazioni dell'insegnamento di LABORATORIO DI FISICA II – Modulo "CIRCUITI ELETTRICI" - del cds 2124 -SCIENZE FISICHE, Anno Accademico 2025/2026.

- Visto l'articolo 17 del regolamento dei corsi di dottorato dell'Università degli Studi di Palermo;
- visto il parere positivo espresso dalla Prof.ssa Alice SCIORTINO, responsabile dell'insegnamento di LABORATORIO DI FISICA II – Modulo "CIRCUITI ELETTRICI" (6 CFU)
- visto il parere positivo espresso dal Prof. Simonpietro AGNELLO, Tutor del Dott. SANGIORGI,

il Collegio dei Docenti, **all'unanimità, approva** la richiesta dell'allievo Emanuele SANGIORGI.

In merito all'attività di didattica integrativa svolta dai dottorandi, il Prof. Paternostro, in qualità di delegato alla didattica del Dipartimento di Fisica e Chimica, espone le problematiche degli insegnamenti di laboratori nei corsi di laurea incardinati nel Dipartimento: l'alto numero di studenti, di gran lunga maggiore della capienza dei laboratori, impone spesso delle turnazioni con conseguente aggravio di impegno per il docente responsabile del laboratorio. Dopo ampia discussione, il collegio propone che poiché l'attività di didattica integrativa dei dottorandi include l'assistenza in laboratorio,

essa venga riconosciuta e autorizzata nei casi in cui se ne faccia richiesta. In particolare, laddove un docente di un insegnamento di laboratorio espone al proprio CdS l'esigenza di avere un assistente in laboratorio, tutti i dottorandi verranno informati e potranno avanzare la loro disponibilità, allegando il parere positivo del proprio tutor. Per accelerare i tempi, il collegio dà mandato al coordinatore di approvare con un decreto la richiesta del dottorando, il decreto sarà portato a ratifica nella prima seduta utile del collegio.
Il Collegio dei Docenti **approva all'unanimità** la proposta emersa dalla discussione.

4) Ratifica decreti

Il coordinatore comunica che per motivi di urgenza, ha emanato il seguente decreto:
Nullaosta per il Dott. Alessandro Salvatore TRAMUTO a svolgere attività didattica integrativa, per un totale di 28 ore, nell'ambito delle esercitazioni dell'insegnamento di METODI NUMERICI PER LA FISICA - Anno Accademico 2025/2026.

Il Collegio dei Docenti, **all'unanimità, approva** la ratifica del decreto.

Il verbale è approvato seduta stante. La seduta si chiude alle ore 16:30.

Il Presidente
Prof. Marco Cannas

Il Segretario
Prof. Simopietro Agnello

Allegato 1

PHD IN PHYSICAL AND CHEMICAL SCIENCES, XXXVIII COURSE

PhD Candidate: Francesco Barra

Transcript of Records

Tutor: Prof. Tiziana di Salvo

Cotutor: Dr. Ciro Pinto

Courses/school/exam scores:

- Astrophysics laboratory of thermal X-ray plasmas, Dr. Ciro Pinto
- Millisecond Pulsars: Theory and accretion, Prof. Rosario Iaria
- Quantum field theory in curved spacetime and in noninertial frames, Prof. Roberto Passante and Prof. Lucia Rizzuto

Research and training periods abroad

5/09/2024 - 28/02/2025 (6 months) – Predoc Fellowship: Center for Astrophysics - Harvard & Smithsonian, Cambridge, Massachussets, USA – Tutor: Dr. Peter Kosec and Dr. Laura Brenneman

Papers published

As 1st author:

1. Authors: F. Barra, C. Pinto, M. Middleton, T. Di Salvo, D. J. Walton, A. Gúrpide, and T. P. Roberts
   Title: Examining the nature of the Ultraluminous X-ray source Holmberg II X-1 (2024, A&A)

2. Authors: F. Barra, D. Barret, C. Pinto, T. Di Salvo, N. Weinberg, S. Guichandut
   Title: Line detections in photospheric radius expansion bursts from 4U 1820-303 (2025, A&A)

As Co-author:

1. *Authors*: R. Iaria, T. Di Salvo, A. Anitra, C. Miceli, W. Leone, C. Maraventano, F. Barra, A. Riggio, A. Sanna, A. Manca and L. Burderi
   Title: The puzzling orbital residuals of XTE J1710–281: Is a Jovian planet orbiting the binary system? (2024, A&A)

2. *Authors:* A. Anitra, C. Miceli, T. Di Salvo, R. Iaria, N. Degenaar, J. M. Miller, F. Barra, W. Leone and L. Burderi
   Title: X-ray view of emission lines in optical spectra: Spectral analysis of the two low-mass X-ray binary systems Swift J1357.2–0933 and MAXI J1305–704 (2024, A&A)

3. *Authors*: R. Iaria, T. di Salvo, A. Anitra, C. Miceli, **F. Barra**, W. Leone, L. Burderi, A. Sanna, A. Riggio
   Title: Confirmation of the presence of a CRSF in the NICER spectrum of X 1822-371 (2024, A&A)

4. *Authors*: F. Pintore, G. Rodriguez-Castillo, G.L. Israel, N.O. Pinciroli Vago, S. Motta, **F. Barra**, D.J. Walton, F. Fuerst, P. Kosec, C. Salvaggio, M. Del Santo, A. Wolter, M. Middleton, A. D'A`i, E. Ambrosi, L. Burderi, M. Imbrogno, R. Salvaterra, A. Robba
   Title: A new pulsating neutron star in the Ultraluminous X-ray source NGC 4559 X7? (2025, A&A)

Paper submitted (as Co-author):

1. *Authors*: C. Pinto, S. Caserta, **F. Barra**, Y. Xu, D. Barret, P. Kosec, N. La Palombara, A. Marino, F. Pintore, A. Riggio, T.P. Roberts, C. Salvaggio, L. Sidoli, R. Soria, D.J. Walton
   Title: XMM-Newton multi-year campaign on NGC 55 ULX-1. Resolving the wind and its variability with RGS

2. *Authors*: R. Iaria, T. Di Salvo, A. Anitra, **F. Barra**, A. Sanna, C. Maraventano, C. Miceli, W. Leone and L. Burderi
   Title: A mysterious feature in the NICER spectrum of 4U 1820-30: A gravitationally redshifted absorption line?

Paper to be submitted:

As 1st author:

1. *Authors*: **F. Barra**, C. Pinto, T. Di Salvo et al.
   Title: Probing the spectral evolution of the ultraluminous X-ray source NGC 5204 X-1 (2025b, A&A)

2. *Authors*: **F. Barra**, C. Pinto, T. Di Salvo, S. Caserta, P. Kosec
   Title: Unveiling relativistic outflows in the Ultraluminous X-ray pulsar RX J0209.6-7427 (2025c, A&A)

3. *Authors*: **F. Barra**, P. Kosec, C. Pinto, T. Di Salvo et al.
   Title: A deep insight into the wind properties at different precession phase during Hercules X-1's Short High States (2025d, ApJ)

As Co-Author:

1. *Authors*: Peter Kosec, Laura Brenneman, Erin Kara, Teruaki Enoto, Takuto Narita, Koh Sakamoto, Rudiger Staubert, **Francesco Barra**, Andrew Fabian, Jon M. Miller, Ciro Pinto, Daniele Rogantini, Dominic Walton, and Yutaro Nagai
   Title: XRISM/Resolve observations of Hercules X-1: vertical structure and kinematics of the disk wind (ApJ)

2. *Authors*: S. Caserta et al.
   Title: Unveiling the biconical geometry of the outflow in the ultraluminous X-ray source NGC 5204 X-1 (A&A)

Conferences/workshop attended and seminars:

Talks:

1. *Title: Using X-ray variability to estimate the nature of the compact objects powering ULXs*
   "The first Vasto Accretion Meeting 2023 (VAM 2023)" (June 23, 2023)

2. *Title*: Exploring burst-driven winds during photospheric radius expansion bursts in 4U 1820-303
   Contributed talk for the "The Vasto Accretion Meeting 2025 (VAM 2025)" (June 23, 2025)

Invited talks:

3. *Title*: Using X-ray variability to determine the nature of the compact objects powering ULXs
   Scientific seminar given at INAF-IASF PALERMO (December 12, 2023)

4. *Title*: Using X-ray variability to determine the nature of the compact objects powering ULX
   Scientific seminar given at SEAWIND meeting (October 28, 2024)

5. *Title*: Trajectory of the stellar flyby that shaped the outer Solar System
   Scientific seminar given at Center for Astrophysics - Harvard & Smithsonian (February 20, 2025)

6. *Title*: Exploring burst-driven winds during photospheric radius expansion bursts in 4U 1820-303
   Invited talk at Institut de Recherche en Astrophysique et Planetologie (IRAP), Toulouse (April 11, 2025)

Posters:

1. *Title*: X-ray spectral variability as a probe of the compact objects powering ULXs
   Contributed poster and flash talk at XMM Newton Workshop 2024 - European Space Astronomy Centre (ESAC), Madrid (June 5-7, 2024)

Attended:

1. Attendance in person at the "25 Years of Science with Chandra" symposium, Boston (December 3-6, 2025)

2. Attendance in person at "The 3rd XRISM Community Workshop", University of Maryland, College Park (February 3-5, 2025)

3. Attendance in person at "The 11th Microquasar Workshop «A Microquasar Odyssey: unveiling the Complexities", Cefalù (September 15-19, 2025)

Thesis title: Crossing the Eddington limit in accreting X-ray binary systems

Abstract:

Above 2/3 of all known stars in our Galaxy are in a binary system orbiting around their common center of mass. Some close systems undergo mass transfer in the form of an accretion disc around the compact object which strongly radiates in the X-rays (X-ray binaries, XRBs). Compact objects are black holes, neutron stars and white dwarfs; they represent the ending point of the stellar evolution. Accretion, as well as thermonuclear explosions of accreted matter on neutron star surface, often results in the ejection of matter in the form of a wind blowing away with velocities ranging from 100-1000 km/s to relativistic velocities (0.2c, e.g., in ultraluminous X-ray sources, ULXs, and during type-I X-ray bursts). These winds can be driven by various mechanisms such as radiation pressure, magnetic forces (with a broad range of velocities) or thermally (≤ 1000 km/s), and are characterised by a high temperature ($10^{(5-6)}K$). The observed velocities indicate that they are launched from different regions of the accretion disc, and they partially absorb the source flux. The outflows, therefore, imprint signatures in the source X-ray spectrum in the form of Doppler-shifted absorption lines. Owing to their high velocities, the winds may carry out significant amount of power and angular momentum that is likely altering the evolution of the binary system and inflating the interstellar cavities found around several ULXs and some XRBs. Moreover, these winds might influence the growth of compact objects, whose nature in ULXs remains uncertain in most cases, and the star formation in their surroundings. Despite the fact that winds are closely intertwined with the accretion process, our understanding of their properties, such as mass outflow rate and energetics, remains limited. This limitation arises from their reliance on e.g. the solid angle from which the winds originate and their filling factor (or clumpiness). Additionally, determining this angle is challenging since we typically only observe the winds and sample their properties along a single line of sight. Around the Eddington limit, at the balance between radiation and gravitational forces, dramatic changes are expected to be seen in both the accretion and the ejection flow.

In this thesis, I present the results of my Ph.D research on Eddington-limited and super- Eddington accretion physics, with a particular focus on the associated ejection of matter from these systems triggered by different physical mechanisms, i.e. accretion and thermonuclear explosions. Furthermore, I introduce a novel-method, applied here for the first time, to discriminate the nature of the extragalactic super-Eddington accretors, from which constraints on the mass were derived. The following thesis is composed of nine chapters.

The first three chapters provide an introduction to the theory of accretion in sub- and super-Eddington regimes, and the type-I X-ray burst physics.

Chapter four presents an overview of the X-ray observatories, the principles of X-ray spectroscopy of the continuum and plasma modelling, and the data analysis methods employed to detect and characterise the outflows.

Chapter five presents an analysis of the disc wind properties in Hercules X-1, a distinctive X-ray binary system featuring a precessing warped accretion disc. This study provides the first observational constraints on disc winds during its Short High state and to complete the sampling of the outflow properties, for the first time in literature, at different inclination angles.

In chapter six, I investigate the outflows occurring during type I X-ray bursts that exhibit photospheric radius expansion in 4U 1820-303, reaching and surpassing the Eddington limit expected for neutron stars.

Chapter seven and eight focus on the study of the spectral variability and a systematic search for disc wind in a small sample of ULXs, powered by super-Eddington accretion onto extragalatic stellar-mass black holes and neutron stars, such as Holmberg II X-1 and NGC 5204 X-1. In this context, I introduce an innovative method for discriminating the nature of these compact objects.

The final chapter summarises the key findings of this thesis and outlines future research directions in this field, particularly in light of upcoming X-ray observatories.

The PhD Board Dean

Prof. Marco Cannas

Marco Cannas

Allegato 2

PHD IN PHYSICAL AND CHEMICAL SCIENCES, XXXVIII COURSE

PhD Candidate: Amedeo Maria Favitta

Transcript of Records

Tutor: Roberto Passante

Cotutor: Lucia Rizzuto

Courses/school/exam scores:

- **Numerical methods for out-of-equilibrium statistical physics by professors D. Valenti and G. Cottone, mark A**
- **Open Quantum System and quantum machine learning by professor S. Lorenzo and Dr. L. Innocenti, mark A**
- **Quantum field theory in curved spacetime or non-inertial frames by professors R. Passante and L. Rizzuto, mark A**

Research and training periods abroad

- COST Action CA20016 Training School (LapTh, France) 2025 Cosmic WISPers: Light Dark Matter Physics
- 1st UNDARK Scientific School 2025 Astrophysical and Cosmological Probes of BSM, Benasque Science Center
- COST Action CA20016 Training School 2024 Cosmic WISPers, University of Ljubljana, Slovenia

Papers published:

- **A. M. Favitta, I. Brevik, M. Chaichian, Axion Electrodynamics: Greens Functions, Zero-Point Energy and Optical Activity, Annals of Physics 455, 169396 (2023). doi:10.1016/j.aop.2023.169396**
- **I. Brevik, A. M. Favitta, M. Chaichian, Axionic and Non-Axionic Electrodynamics in Plane and Circular Geometry, Phys. Rev. D 107, 043522 (2023). doi:10.1103/PhysRevD.107.043522**
- **I. Brevik, M. Chaichian, A. M. Favitta, On the Axion Electrodynamics in a Two-Dimensional Slab and the Casimir Effect, Int. J. Mod. Phys. A (2024). doi:10.1142/S0217751X24500040**

Papers in preparation

- **A.M. Favitta, R. Passante, L. Rizzuto, "Cosmological bounds on scenarios of axion-like particles and condensates from non-equilibrium QFT", (2025)**
- **M. Campello, A.M. Favitta, R. Passante, L. Rizzuto, "Effects of axions on Casimir-Polder forces" (2025)**
- **A.M. Favitta, "Axion domain walls and thermal friction", PoS - Proceedings of Science (2025)**

Conferences/workshop attended:

- **Talks:**
- **20th Patras Workshop on Axions, WIMPs and WISPs, IAC & University of La Laguna, Tenerife (2025)**
- **13th Young Researcher Meeting, University of Palermo (2024)**
- **19th Patras Workshop on Axions, WIMPs and WISPs, University of Patras (2024)**
- **PIERS 2023, Prague (2023)**

- **Posters:**
- **Axions in Stockholm, Nordita, Stockholm (2025)**

- **Participations**
- **"Axions and gauge fields in the early and late universe", Nordita, Stockholm (2025)**
- Working Group Meeting of COST Action COSMIC WISPers (CA21106), Kirchhoff institute, Heidelberg(2025)

Thesis title: Non-equilibrium Quantum Field Theory and Axion Electrodynamics in curved spacetimes

Abstract:

Axions are a class of hypothetical fundamental particles introduced formerly as a possible solution to the Strong CP problem of Quantum Chromodynamics (QCD) by Roberto Peccei and Helen Quinn in 1977, but have also been obtained in several low-energy compactification models of String Theory.
Various astronomical and experimental constraints imply that the axion is 'invisible' in the sense that its interactions with Standard Model (SM) particles are significantly weak, and this is why the axion is regarded as a viable candidate as a Dark Matter component.

In this thesis, we discuss our new results on the topics that have been developed during the three PhD years, in particular on Axion Cosmology and Axion Electrodynamics, research areas of strong

interest nowadays, where the production of axion particles with their topological defects, along with the interaction between SM particles and the axions themselves, are respectively studied and
have been the object of published papers and conference and workshop presentations. Our investigations will be also based on original methods and results in non-equilibrium Quantum Field Theory and in Quantum Field Theory in curved spacetimes.

These topics are addressed in the present PhD thesis. We first review the basics of Quantum Field Theory in curved spacetimes and some elements of Cosmology. We will introduce the Strong CP problem in the Standard Model of particle physics , which heavily suggests the introduction of a new particle, the QCD axion. This includes the Peccei-Quinn solution for the strong CP problem in QCD, the first Peccei-Quinn-Wilczek-Weinberg (PQWW) axion model, and the invisible QCD axion models.
Furthermore, we analyze the two main classes of ultraviolet (UV) completions to QCD axion theory: the "field theory" completion models and the extradimensional ones, related both to the so-called "quality problem" for the axions and the last one justifying the possible existence of further axions, known as axion-like particles (ALP).

These introductory parts of the thesis are relevant for understanding the current state and problems in the literature of the axions and quantum field theory in curved spacetimes, and in particular to understand and put in the right perspective the relevance of our original results, new theoretical findings and new experimental methods.

We first investigate an important and interesting aspect of Axion physics, namely Axion Electrodynamics.
Axion Electrodynamics is the study of the modification to Electrodynamics due to the presence of an interacting classical axion field. It is deeply connected to applications for axion detection, as many of the most promising experiments for detecting the axion exploit a strong magnetic field, and in the present day we expect a more significantly classical behavior for a DM axion field, notwithstanding some recent claims of stochasticity from surviving axion miniclusters, which can be taken care of in the future.
However, Axion Electrodynamics is also related to the theoretical aspects we deal with in the involved Axion Cosmology case, particularly energy-momentum conservation and the interplay between the condensate and particle kinetic regimes.
Furthermore, we study some aspects that are less investigated in the literature, such as the effects of the axion field on electromagnetic Casimir forces. This leads to modifications of dispersion relations and zero-point energies that could be detected by Casimir force experimental setups or by astronomical observations.
We found the study of the Casimir force for a spatially dependent axion field to be of remarkable interest, as it is deeply connected to cosmological thermal friction.
In particular, we will first consider the basic aspects and the modifications to Maxwell equations, along with energy-momentum conservation. Then, we will analyze the cavity haloscope models and the Green's functions in Axion Electrodynamics. This last theoretical aspect is relevant to treat the applications we will discuss, which are the Casimir physics, the thermal friction on an effective axion domain wall and the optical properties of the axion medium

We then investigate the non-equilibrium quantum field theory dynamics of a self-interacting axion field interacting with a generic Standard Model sector or a Dark Sector, considering the path integral approach and the 2PI effective theory. We investigate the connection and validity of several approximations adopted in the former literature, such as the non-relativistic and relativistic approximations, classical field, average field, condensate and particle kinetic regimes,

along with stochastic scenarios. We demonstrate that the nPI approach enables us to extend previous approaches, adopting explicitly or implicitly perturbation theory such as the Schrödinger -Poisson and the Velocity-One scale analytical models, and overcome the limitations due to their approximations, in particular in the dynamical regimes where non-linear effects are relevant.

We use these results for applications to two main cosmological scenarios.

The first one is the preinflationary scenario for high-mass photophilic ALPs, for which we will discuss the cosmological constraints on the parameter space in particular in the region of the high-mass axions with $m_a > 10\ keV$, from the contribution to ΔN_{eff} due to the irreducible axion freeze-in production.
We will secondly consider the postinflationary scenario for the QCD axion and high-mass photophilic ALPs. We discuss the Domain Wall problem for such models and analyze the dynamics of the networks of axion topological defects, in particular domain walls. This is obtained from the current analytical models based on the Velocity-One scale framework and their extensions we have obtained through non-equilibrium Quantum Field Theory methods.

This last method uses an extension of the moduli space quantization, by considering the domain wall solutions with center-of-mass velocity $\vec{v}$ and quantizing the axion field as a superposition of them, instead of the usual "particle" mode functions.
This method also allows us to further discuss the validity of the classical field approximation and its connection with stochastic approaches to cosmological dynamics.
We finally analyze the friction effects for the photophilic ALPs due to the interaction with the SM primordial plasma by taking care of the plasma effects, that we claim to originate mainly from electrons and muons; we also discuss the validity of our model and the connection with former literature.

The PhD Board Dean

Prof. Marco Cannas

Marco Cannas